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TWO CONCEPTS OF ENOUGHNESS AS ORGANIZING DESIGN PRINCIPLES FOR GENERATIVE STEM EDUCATION AND CULTURALLY SITUATED DESIGN TOOLS

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Abstract. The concept of *enoughness* holds importance for both African American and Indigenous communities. In Indigenous contexts, ideas of enoughness can be about moving from extractive to sustainable economies where balance, interdependence, cooperation, and decentralization are prioritized in the production and sharing of resources. In African American contexts enoughness is about challenging deficit views of Black children as maladjusted and incomplete with an insistence that people, especially educators, see their existing brilliance and celebrate the fact that they are already enough. We explore how these concepts shaped efforts to make science, technology, engineering, and mathematics (STEM) education more equitable, justice-oriented, and generative, thus re-thinking the shape of STEM itself as a platform for generative justice. We detail how this was accomplished through designing and researching educational technologies called Culturally Situated Design Tools.

Keywords: *STEM education, culturally situated design tools, enoughness, generative justice*.

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1. Introduction

In this paper, we explore different concepts of *enoughness* as pathways for re-thinking STEM education. African American and Indigenous scholars, activists, and communities have used the term to mean different things. In Indigenous contexts, enoughness is about moving from extractive to sustainable economies where balance, interdependence, cooperation, and decentralization are prioritized in the production and sharing of resources (First People World Network, 2013; Simonelli, 1994). In African American contexts enoughness is about challenging deficit views of Black children as maladjusted and incomplete with insistences that people, especially educators, see their existing brilliance and celebrate the fact that they are already enough (Woodson & Love, 2019; Woodson, 2021). While there is no reason why these two concepts need to be connected or put into conversation—they are already enough on their own—we explore how they can be mutually supportive in efforts to make science, technology, engineering, and mathematics (STEM) education more equitable, justice-oriented, and generative, thus rethinking the shape of STEM itself as a platform for generative justice.

In working with African American and Indigenous communities in the design of STEM educational activities and educational technologies called Culturally Situated Design Tools, the research group that the two authors (Babbitt & Lachney) are part of has endeavored to maintain multi-directional bridges between Western and non-Western knowledge systems. From this work, the two concepts of enoughness emerged as core principles: acknowledging that Black and Indigenous children are already enough by working with local communities to create generative systems that connect education to local economic and cultural activities. Our work explores how these processes can challenge value extraction and assimilation. We will begin by explaining the concepts with supporting examples before showing how they emerged as mutually supportive in a number of generative STEM education projects.

2. Two pathways for Enoughness

Educational research on Black children in the United States has long trafficked in “gap” language, most notably the achievement gap (Carey, 2014). Woodson & Love (2019) argue that within school systems mired in White supremacy, gap language creates an ontological relationship where Black children’s potentialities and futures are measured against the benchmarks of White children’s. This type of framing completely misses the histories of political disenfranchisement, economic segregation, and state violence that shape the racialized conditions of today. As Ladson-Billings (2006) notes, instead of a gap a better term for describing Black communities’ relationships to education might be *debt*. Debt has a temporal element that may be missed if the gap is only interpreted spatially (e.g., “mind the gap”), while also flipping the directionality of who needs to change: it is not African American communities that need to necessarily change but, instead, the educational, political, and economic systems that reproduce anti-Black racism. Out of this recognition, the idea of *enoughness* emerges to challenge the way that gap language frames Black children as insufficient, deficient, and incomplete. Woodson (2021) poses an alternative: “Celebrate enoughness. Celebrate the child who cared for siblings as often as you celebrate the child with perfect attendance” (20). There is room for care, attendance, and more when educators recognize that Black children are already enough.

Indigenous communities also provide insight into the concept of enoughness, with a focus on ecological sustainability to ask, in the words of the photographer and conservationist Mittermeier (2014), “how much is enough?” This idea of enoughness is about humor, play, and individual senses of accomplishment. It is also about building a sustainable economy where humans are not at the top of the hierarchy but in balance, interdependence, cooperation, and reciprocation with other living and nonliving things—something that Western knowledge production often misses (Simonelli, 1994). Enoughness points to the generative economies of Indigenous communities that challenge Western ideas about individuals fighting against each other in competition for resources (First People World Network, 2014). For example, enoughness is at the core of *One Dish One Spoon*, a law used by Native Nations in North America at least since 1142 AD (first recorded instance) to ensure regenerative vitality of natural resources, alongside the flourishing of the peoples who live there (Mann, 1997).

Below we explore the concept of enoughness from both African American and Indigenous communities with three examples: Ghanian adinkra symbols, the concept of ‘One Dish One Spoon’, and approaches to civics education with African American children. We then explore cases where these concepts informed the design and implementation of STEM education.

3. Social mutuality in Ghanaian Adinkra symbols

One of the fascinating questions we can ask in ethnomathematics is: are there some math ideas outside of those created in Europe and through Eurocentric narratives? Consider the adinkra symbol Boa Me Na Me Mmoa Wo (left), which translates to "Help me and let me help you". The upper triangle is missing a square but has an extra circle. The lower triangle is missing a circle but has an extra square. Each has what the other needs to complete themselves. As a social symbol, the meaning is clear: mutual aid. But how do we express that relation in math? At first, the word “symmetry” comes to mind, but reflection symmetry would require that each side is a mirror image; exactly the same. Here they are complements of each other and open to differences, not reflections.

In his comparison between African gift economies and Western commodity exchange, Lee (1984) notes that in the European tradition, you are careful to make sure you pay someone exactly the assumed value of the product. Even in gift-giving, you try to make sure you do not buy someone a gift with a greater value than what they gave you. But the African tradition among the group he studied, the Dobe! Kung was just the opposite. Typically a gift was bought with no exchange. The receiver may, in the future, give a gift, but that would simply be a new act of generosity. The goal of a gift was not to balance out accounts, it was to create imbalance, and thus strengthen mutual obligation. We are constantly told to think of Indigenous cultures as places of homeostasis, negative feedback, and “eternal wisdom that keeps everyone in balance”. But that is a Western mistranslation that converges with imperialism, colonialism, and primitivist portraits of people who never change. Social mutualism is about a constantly changing network of needs and resources, more like a neural net than a see-saw seeking balance. Indigenous geometry, once we develop the eyes to see it, expresses that in ways that can be unfamiliar to Western assumptions.

Back to the adinkra geometry: let's call this new math property “mutuality”. Perhaps if colonialism never happened, West Africans would have created a collection of proofs and theorems based on mutuality, just as Europe did for symmetry. We could start with a definition: two figures are said to be “mutuals” if their parts can be exchanged to create two completed wholes. There are still some details to work out (how do we define “parts”? or “completed”?). But assuming those challenges can be solved, it might open up new ways of thinking. Can mutuals be in sets of 3 rather than pairs? In higher numbers? Could they be fractional or statistical (“figure A is an 82% mutual to figure B”)?

Of course, the ultimate expression of mutuality would be engineering the entire social-technical economy in that way (Eglash *et al*., 2020). But it is important to help students understand that Indigenous knowledge should not be understood in opposition to STEM. Nor is it merely a rudimentary step up a long ladder that Europe already climbed. Rather, different knowledge systems are more like biological evolution’s branching tree than a ladder; capable of raising new kinds of questions or approaching them in new ways.

4. ‘One Dish One Spoon’ as Enoughness

The use of ‘One Dish One Spoon’ in treaties between Indigenous nations and neighboring groups in North America is a recognition of the finiteness of the natural world from which we all need to draw our sustenance (Simpson, 2008). In general, the practice is to take only what you need, leave some for others, and we all have a responsibility of stewardship over and protecting the environment we live in and rely upon. In addition to the responsibility of environmental stewardship, the phrase can also be taken as a powerful metaphor for justice that is so obviously lacking in our world today. As Potowatami scholar Robin Wall Kimmerer puts it (Swan, 2019), “there isn’t a little bitty teaspoon for some people and a great big ladle for people.” To explore this further, we turn to the Haudenosaunee Thanksgiving Address, which is relevant to thinking about new and different futures (Hill 2020).

The Haudenosaunee Thanksgiving Address (Ohen: ton Karihwatehkwen) is the statement of thanks which is stated at the beginning of any gathering, referred to as ‘words before all else’ (Stokes, 1993). The address begins with a recognition of the people who have gathered for the meeting and goes on to enumerate the bounty and agency of the natural world. The speaker states a passage and the people respond in agreement, creating a gathering of people of one mind. The full ceremony can take many hours to complete and is a good starting place to recognize the fundamental truth that we need to consider how our actions and the actions of others affect the world around us. From their view, our Earth Mother shares her bounty with all creatures that dwell upon her, not just a chosen special few - this includes all of the two-leggeds (people), four-leggeds (animals), the wingeds (birds), and plants and fish, etc. The four winds and other natural forces are similarly endowed with the kinds of inalienable rights, agency, and potential for benevolence that the Western view (sometimes) bestows to (some) humans.

5. Black Children and Civics Education

Woodson & Love (2019) describe the idea of enoughness as a counter to gap language in US civics education. Specifically, they are responding to Levinson’s (2013) assertion of the civic empowerment gap in which Black children are framed as less empowered than White children. This idea of civic empowerment assumes that civic engagement is the same for Black and White children despite the long history of political disenfranchisement in the US. For much of US history, Black and White communities in the US have had differential access to political and civil power, shaping civic commitments and actions. Woodson & Love (2019, 93) explain,

> “Comparing Black children’s (understandably critical) civic attitudes to the more positive civic orientations of many middle-class White children makes Black kids appear disengaged, hopeless, nihilistic, and apathetic. It serves to legitimate character education, citizenship education, and other curricular interventions intended to instill neoliberal patriotic values.”

Historically, if Black children were not deprived of education, schools sought to assimilate them into the White middle-class status quo, a well established colonial strategy of US schooling (Spring 2016). Schools often serve a similar function today, reproducing deficit orientations of Black children as insufficient and incomplete (Emdin, 2016). Woodson & Love (2019) are saying that some framings of civics education are no different and, instead, we should view Black children as already enough.

The enoughness of Black children in civic life is not hard to find. For example, consider fighting against anti-Black discrimination of natural hair, African style headwraps, and durags. In 2018 Oklahoma students noticed a pattern of Black students being disciplined for wearing African-style headwraps (Somvichina-Clausen, 2019). Even after a child who was singled out for wearing one explained that it was of cultural significance the concerns were ignored. Students continued to wear the headwraps in protest and brought the issue to the school board. Eventually, the students' persistence gained media attention and the policy was revoked.

In 2019 in Pasadena California, Black students walked out in protest over their high school's dress code, banning durags, which the school said was associated with gang activity (Lindahl, 2019). The students argued that the policy further criminalized Black boys and men on their school campus. Students were explicit that their fight against the policy was a fight against Black men not being seen as "good enough." Not only were these students showing that their civic engagement was enough but they were also demanding that schools recognize that they, as Black boys, are enough. As a member of the school's Black Student Union explained to a local reporter, "In the now, you have people embracing their culture within their natural hair… In the past, men used to perm their hair and now you have Black men wearing short hair with waves" (Lindahl, 2019, para 7-8).

6. Initial Experiments with Culturally Situated Design Tools

Our STEM outreach program, Culturally Situated Design Tools or CSDTs (https://csdt.org) for short, did not initially focus on concepts of enoughness. Rather, it started with the work of Ron Eglash, who had observed the fractal patterns present in African architecture. He studied this connection while on a Fulbright scholarship in West Africa, and his research resulted in his book *African Fractals* (Eglash, 1999). Likewise, he noticed that fractal patterns also appeared in the African American practice of cornrow hair braiding, along with geometric transformations such as translation, dilation, and rotation. With the support of the National Science Foundation, Eglash and Audrey Bennett formed a research group at RPI to study the STEM content in these and other cultural practices, resulting in the Culturally Situated Design Tools website. The two authors primarily write this paper based on their work with Eglash and Bennett on designing and implementing the CSDTs. Babbitt is a White man who has a background in mathematics, computer science, and educational technology. Lachney is a White man who has a background in media and technology education and the cultural studies of technology.

The tools on the website evolved and expanded over time. The technology started out as a group of Adobe Flash-based programs primarily teaching the mathematics content in various cultural practices. In successive NSF grants, the tools were rewritten as Java-based web applets to teach programming, adding an interface that included a blocks-based programming language similar to MIT's Scratch. Web applets gave way to JavaScript and the adoption of Berkley's Snap! as CSnap! (Culture + Snap). The CSnap! blocks-based programming language added both greater functionality and stability to the tools. Currently, the Scratch 3 interface is under development and may eventually replace the CSnap! implementation. As the web technology in use evolved, the number of tools available also expanded thanks to the work of the CSDT research team. Starting from African Fractals and Cornrow Curves, there are now over two dozen CSDT tools available on the website that highlight the computational and mathematical significance of Indigenous and vernacular designs.

Today, CSDTs are now a suite of computer tools, online simulations, hardware kits, and other technologies based on the idea that STEM concepts such as mathematics and computing can be found in Indigenous and everyday knowledge-keeping systems. African Fractals and Cornrow Curves as mentioned above, are just two of many CSDTs that allow students to explore STEM through a cultural context. All CSDT tools provide background pages for students to read and learn about the history of the practice. These pages are often created with artisans and community partners involved with the cultural practice. This collaboration with artisans ensures that we are both authentic and respectful in the portrayal of the practice and includes the right of refusal should the artisan or partner disagree with the proposed background information. We are always mindful to fight against both cultural appropriation and extraction of Indigenous knowledge during the development of a CSDT.

Following the background information concerning the practice, students will find a tutorial on how to use CSnap! to simulate the cultural design in software. Some CSDTs, such as pH Empowered do not make use of CSnap!, but make use of other hardware instead, such as the open-source Arduino Microcontroller and pH probes. If the CSDT is centered around a physical craft, there is usually physical rendering instructions available which take the student from physical (the cultural practice), to virtual (simulation in CSnap!), back to the physical, producing a replica of the students' design as a crafting activity.

The first goal of the CSDTs is to diversify the input to the STEM pipeline by reducing the barriers to participation for underrepresented students in STEM disciplines. While we recognize that some barriers fall well outside of our control, the myth of genetic determinism is one barrier we actively seek to address. Genetic determinism is the false belief that some people are born predisposed to learning STEM thanks to some mythical “math gene”. Of course, there is no “math gene”, and we believe that this notion can be combated with culturally situated learning opportunities offered by the CSDTs. In addition, truth-telling in delivering the background information of each tool helps to convey acknowledgment of and support for an underrepresented students’ lived experience in their community rather than denying that experience with a White-washed version of history, which oppresses and silences youths of color.

The second goal of CSDTs is to diversify the output of the STEM pipeline (Eglash *et al*., 2020). If we now have more Indigenous, Black, and Latinx scientists and engineers, but their factories are churning out the same old pesticides, nuclear bombs, and rich-get-richer computing platforms, what have we really changed? To that extent, we have developed intergenerational collaborations in which younger participants utilize digital fabrication, sensors, solar energy, and other technologies, and older participants contribute traditional knowledge, techniques, plant species, physical algorithms, and other cultural resources.

7. Translating systems theory from Indigenous to High Tech frameworks 1: enoughness in economic systems and the threats of AI and automation

Many of the CSDTs embody enoughness and other Indigenous principles in this combination of educational and developmental tools. In AI, for example, a research team at the University of Michigan developed a system for detecting the difference between hand-woven and factory-made textiles (Robinson *et al.*, 2020), using the example of kente cloth weaving in Ghana. The adult economy goal is to have this system available for tourists, so that they are not fooled into buying factory fakes. But it is also an opportunity to connect buyers to creators. Ideally, the system will let users know "there is a style similar to this in the village of [xyz], and I see one of their weavers has volunteered to greet customers via whats app; would you like me to connect you?" That is to say, it is a kind of prosthetic to restore the generative loop that traditional economies enjoyed. Such connections might evolve into a visit from the weaver to a classroom.

Because this is not yet ready for use by children, our experiments for authentication needed another means in the educational context. During a visit to the Rensselaer Polytechnic Institute from Harlem Academy, a private school in New York City that primarily serves Black and Latinx students, 8th-grade youth explored the general problem of factory-made fakes. They created a presentation on their research, which ranged from the use of fake Navajo designs by the company Urban Outfitters to the Smithsonian store's fake Gees Bend quilts, made in factories overseas.

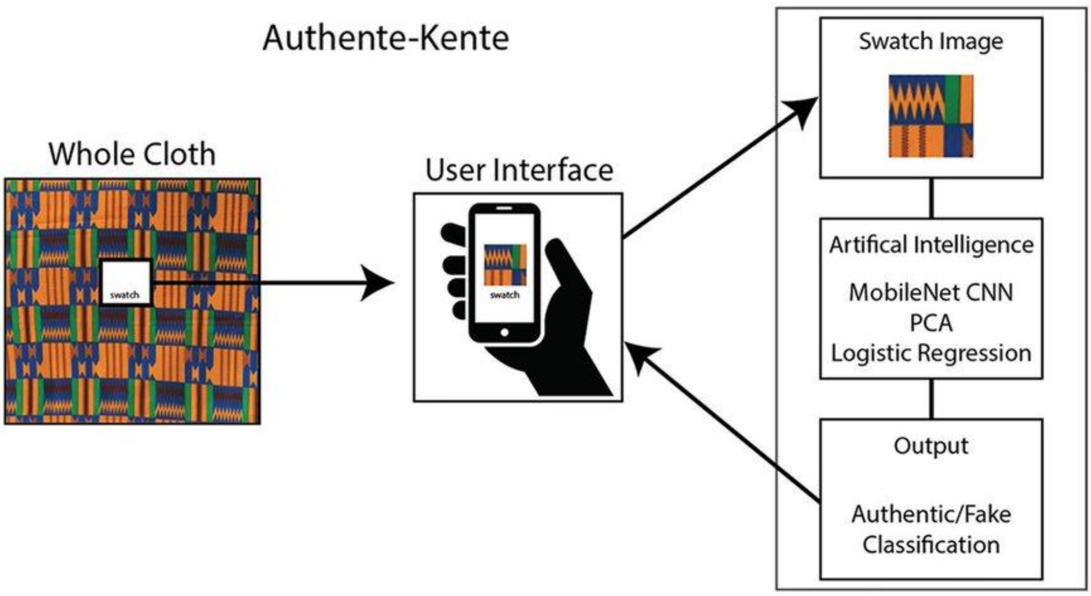

Figure 1. The AI system for authenticating hand-woven kente (from Robinson *et al.*, 2020)

We then had students experiment with the concept of pattern matching used by RFID, QR codes, or other authentication systems. The problem is that those appear somewhat 'magical'—it is impossible to see what is actually being matched if you only have a tiny metal thread woven into the fabric. So we developed a version that was very physical and literally hands-on: gluing magnetic reed switches on one side of a paper plate, and permanent magnets on another. A checkered cloth stood in for the hand-woven fabric (figure 2). By connecting the reed switches in series, the children learned to create a circuit such that every magnet had to be exactly positioned over every switch.

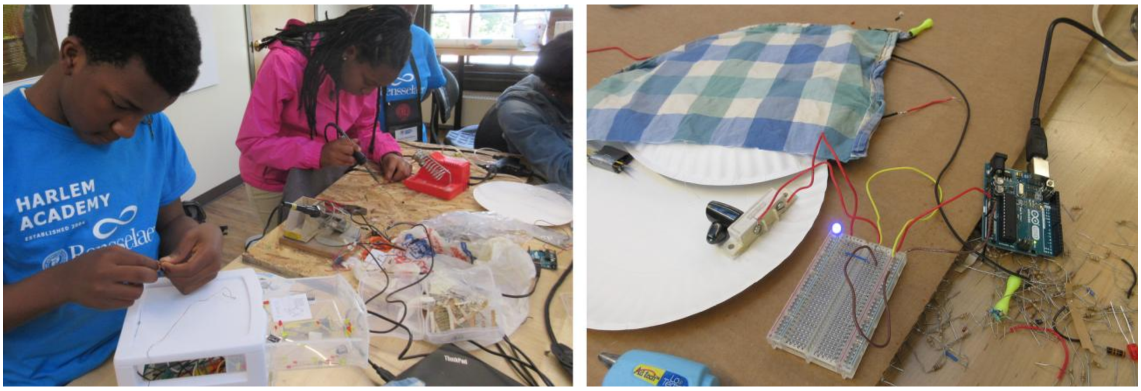

Figure 2. Building and testing the magnetic sensor for authentication

8. Translating systems theory from Indigenous to High Tech frameworks 2: enoughness in environmental engineering

In the case of our authentication system, the Indigenous knowledge aspect is entering into the design practices in a rather oblique way: as an economic principle, factory fakes violate enoughness. The technology connection is framed as assistive. In the case of Indigenous concepts of the environment, the connection is much more direct. Quoting from the CSDT website:

> "Before colonization, Indigenous groups had established principles that kept humans and nature intertwined in complex but balanced relations. "Engineered landscapes" such as controlled burns, clam gardens on the Pacific coast, and agricultural islands in Mexico's lakes created artificial ecosystems that were both productive and sustainable. The science of aquaponics has recreated this approach by mixing fish cultivation and hydroponic plant growth."

The CSDT website on Engineered Ecosystems provides simulations, experimental apparatus instructions, and other materials for understanding what is meant by the concept of "engineered ecosystems." It is essentially making a case for a system of Indigenous knowledge that binds together spiritual practices, harvests from nature, and manipulations of water, land, forests, and other components to enhance human-nature relationships. This poses a challenge in how we translate from Indigenous to Western frameworks. For example, the goal of Western engineering is often expressed as "optimization." Calculating how to optimize profit is often the basis for making nature bear the cost of pollution or workers bear the cost of health care. On the one hand, we have to be able to translate enough of the Indigenous knowledge system to make this worth teaching in the classroom. On the other hand, we have to maintain the integrity of the Indigenous perspective. "Enhance human-nature relationships" is not the same as "optimize for profit".

As Eglash (1995) has shown, cybernetics has been an especially useful way to translate between those domains. For example, feedback loops can be used in cybernetic engineering to maintain balance for something as simple as a thermostat. Indigenous principles such as *hózhó* (Navaho for beauty, peace, and wellness) *and bimaadiziwin* (the Anishinaabemowin word for "the good life"*)* are essentially naming forms of balance that have similar implications. This balance framework helped to prevent environmental degradation and wealth inequality, supporting the concept of enoughness.

Figure 3. Feedback in rice simulation

One way of helping students to translate between domains is through the use of simulations. The Engineered Ecosystems website introduces students to techniques Anishinaabeg used to maintain water levels best for wild rice growth, a culturally and nutritionally significant species in the traditional economy. Figure 3 shows a simulation in which students are controlling a "green tourism" site based on Anishinaabeg wild rice. The presence of too many tourists and you have eutrophication of the lake; too few and not enough rice is maintained. Finding the balance point is essentially demonstrating both a feedback model and Indigenous ecosystem knowledge.

Many Indigenous communities today continue to use engineered ecosystems in their quest to restore balance for their people. One of these systems combines both hydroponics, the cultivation of plants in water with aquaculture, raising fish, shrimp, and other water creatures in pools of water. Nutrients excreted from the fish are absorbed by the plants that, in turn, filter the water for the fish. The Anishinaabemowin word *bimaadiziwin* fits well with these approaches to growing food.

In 2018, our research team participated in a summer workshop held at Northern Michigan University, sponsored by the Center for Native American Studies. Attendees learned about aquaponics and conducted research on how they might theoretically use aquaponics to help meet the nutritional needs of a community. They designed their systems based on the calorie requirements of the people it would serve and then theorized how the system would be constructed.

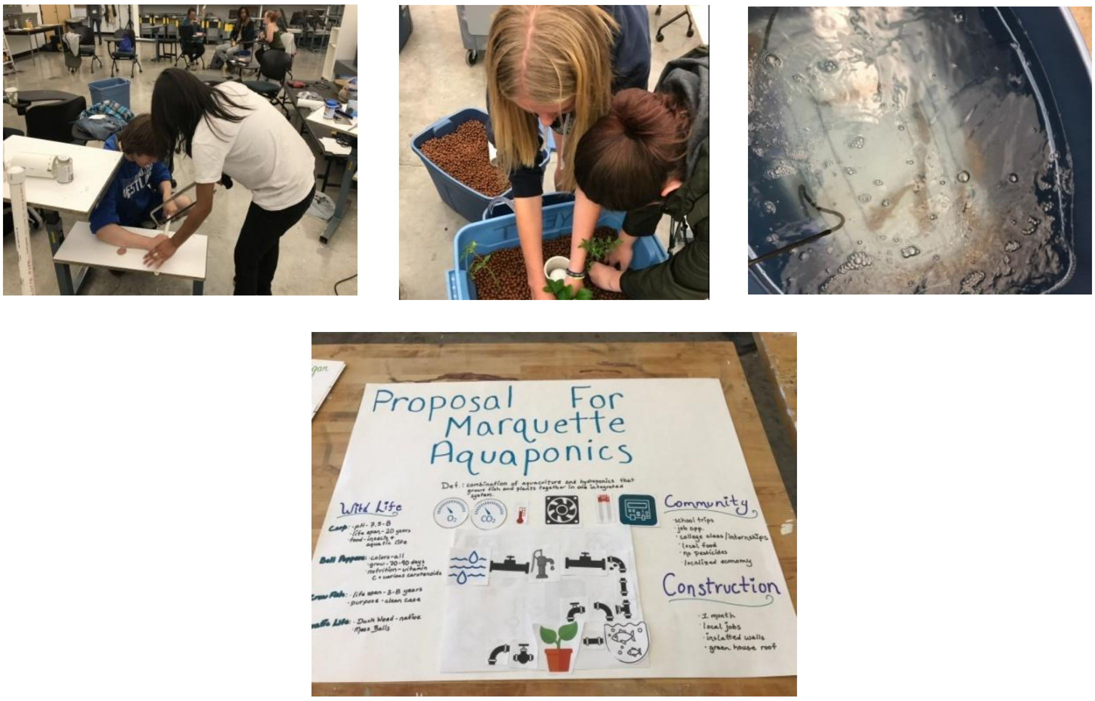

Figure 4. Young people construct aquaponic structures

As shown in Figure 4 above, students then went on to construct demonstration units to experience the challenges of building aquaponic structures. To construct their aquaponics system, the students used a set of plastic bins to house their fish and plants. A large bin served as the base to hold some locally acquired baitfish, and a smaller bin, placed across the top of the bottom one, was filled with growing media to support the plants. Each of the groups presented their research to the whole group, completing the workshop. Future collaborations might include a greenhouse with aquaponics for both community and educational use.

9. Translating between mathematics and knitting: enoughness in the classroom

For four months in 2014, we (Babbitt and Lachney) spent time with a 7th-grade knitting club made up of mostly Black girls to explore how we might make connections between mathematics and knitting for a new CSDT. We went in with the assumption that this would help the students make connections that they did not already have. However, we found that this was the wrong framing, as the girls were already demonstrating knowledge about how to think mathematically about knitting without our help.

During lunch, most days of the week a teacher would invite a group of girls up to her classroom to knit. While the primary goal of the club for the teacher and students was to learn to knit, the club also acted as a space to connect the act of knitting to mathematics and fiber sciences. Some of the girls had substantial experience knitting, while most were working with needles and yarn for the first time. To teach students knitting, the science teacher prompted them with the prospect of making scarves and headbands, and later on with knitting design challenges.

Students' goals and intentions varied as to why they wanted to knit. Some students wanted to add to their wardrobe, others knitted for siblings and family members, and most were also there to socialize with peers. While our goal was to explore how to connect mathematics to knitting, superimposing this on existing practices, we also found that in some cases students were already engaging with mathematical ideas while knitting. Specifically, mathematics emerged from the knitting practices while students were trying to determine their gauge. Gauge refers to the number of stitches per inch or increment. Gauge is an entanglement of the knitter, yarn, and needles that determines how tight and loose to make the stitches.

Tonya (pseudonym) demonstrates clear intentions for how to control the needles and yarn beyond just thinking about being tight or loose with one's hands when determining gauge. She uses a geometric triad of triangle, square, and trapezoid to determine gauge. Her needle and yarn are differentiated by the way that she shapes her needles in relation to either an imaginary line or her fingers across the ends, thus completing the intended shape: "…if your hands like this, like close like a triangle then it's tight, but being like this like a square it is too loose, so you gotta be like in the middle like a trapezoid." (see Figure 5). While we, as researchers, went into the club thinking we were going to illuminate mathematical elements of knitting for students; the relationship was not so unidirectional. Instead, students and researchers entered into a collaborative multi-directional relationship of reciprocal learning with each other.

Figure 5. Tonya explains how she determines gauge

10. Conclusion

This paper has examined how different concepts of enoughness helped make our educational technology design, implementation, and research generative. CSDTs are a dynamic set of tools available for free on the internet. The tools expose STEM topics through the cultural practices where those topics can be found. They provide an opportunity to learn all about the cultural background of the practice, simulate the physical artifacts while learning to program, and then physically render student designs as craft activities. The tools are under active development and are expanding to include open-source hardware such as the Arduino microcontroller and related sensors, digital fabrication devices, and so on.

But as the site has evolved, we have begun to address the broader problem that STEM itself—the industrial-scientific complex—is generally made for the purpose of extracting value. Diversifying the input to the STEM pipeline is not sufficient; we must diversify its output as well. Envisioning STEM based on enoughness—a generative form of STEM that treats people, nature, and technology as collaborators in an effort to ensure equal flourishing among all parties—means integrating the more sophisticated outlooks from Indigenous origins, social justice movements, and other sources into the very fabric of the science and technology enterprise, thus offering a transformative vision for STEM education.

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